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**CARBON FIBER HEATING ELEMENT ASSEMBLY
AND METHODS FOR MAKING**

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CARBON FIBER HEATING ELEMENT ASSEMBLY AND METHODS FOR MAKING

Field of the Invention

[0001] This invention relates in general to heating element assemblies and deals more particularly with improvements in non-metallic heating element assemblies of electrical resistance type.

Background of the Invention

[0002] The present invention is particularly concerned with improvements in non-metallic heating element assemblies and particularly electrically conductive carbon fiber heating element assemblies suitable for general purpose usage in a wide variety of heating applications.

[0003] The development of improved processes for artificially producing staple carbon in fibrous or filamentary form and at reasonable cost has virtually revolutionized the plastic composite industry, particularly where light weight and a high degree of mechanical integrity is desired. New materials embodying carbon in fibrous or filamentary form now enjoy wide spread use in the production of golf shafts, aircraft parts, and indeed entire airframes, to cite a few outstanding examples. Advantages in the use of carbon in the electrical field were early recognized by pioneers in that field, and although artificially produced carbon fiber has found some limited usage in electrically operated heating device, the potential for such usage has not yet been fully realized.

[0004] Accordingly, it is the general aim of the present invention to provide improved electrical heating element assemblies employing carbon fiber technology and suitable for supplying heat in a wide variety of environments both small and large. It is a further aim of the present invention to provide improved carbon fiber heating element assemblies for use in a variety of automotive heating applications as, for example, warming the seats and steering wheel of a vehicle, deicing and defogging windows, outside rear view mirrors and various vehicle engine heating applications.

[0005] A still further aim of the invention is to provide improved carbon fiber heating elements for economic installation and operation to heat large surface areas such as

the floors of up-scale homes, apartments and condominiums, the surfaces of parking lots, sidewalks, driveways, highway sections, bridge decks and airport runways, as well as the surfaces of aircraft which operate thereon.

[0006] Yet another aim of the invention is to provide carbon fiber heating element assemblies, which utilizes to advantage the negative coefficient of electrical resistance (ohm) exhibited by carbon fiber.

Summary of the Invention

[0007] In accordance with the present invention, a heating element assembly comprises an axially elongated longitudinally extending generally flat bundle of substantially rectilinear continuous carbon fibers or filaments of indeterminate axial length. The bundle has a predetermined electrical resistance per unit of axial length and is disposed between generally flat layers of dielectric sheet material arranged in opposing face-to-face relation to each other with one of the layers in direct overlying contacting engagement with and unconnected relation to an associated flat surface of the bundle and the other of the layers adhered to another flat surface of the bundle opposite the associated flat surface. Marginal portions of the layers are connected to each other along the entire axial length of the bundle and immediately adjacent longitudinally extending transversely opposite sides of the bundle, whereby a sheath formed by the layers is sealed against axially transverse migration of moisture through the sheath. The sheath also serves to electrically insulate the bundle.

Brief Description of the Drawings

[0008] Fig. 1 is a fragmentary perspective view of a heating element assembly embodying the present invention.

[0009] Fig. 2 is a somewhat enlarged sectional view taken along the lines 2-2 of Fig. 1.

[0010] Fig. 3 is a fragmentary perspective view showing another embodiment of the invention.

[0011] Fig. 4 is a somewhat enlarged sectional view taken along the lines 4-4 of Fig. 3.

[0012] Fig. 5 is a somewhat schematic side elevational view illustrating a method of making a heating element assembly in accordance with the present invention.

- [0013] Fig. 6 is a fragmentary schematic perspective view and illustrates a method for stripping an end portion of the heating element assembly of Figs. 1 and 2.
- [0014] Fig. 7 is a fragmentary perspective view of the stripped end portion of the heating element assembly of Fig. 6.
- [0015] Fig. 8 is a fragmentary perspective view of a further heating element assembly made in accordance with the invention.
- [0016] Fig. 9 is a somewhat enlarged fragmentary sectional view taken along the line 9-9 of Fig. 8.
- [0017] Fig. 10 is a diagrammatic view of an apparatus for determining the electrical resistance per unit of length of a typical heating element assembly embodying the present invention.
- [0018] Fig. 11 is a diagrammatic view of an apparatus for determining the electrical resistance per unit of length of a test sample at various operating temperatures.
- [0019] Fig. 12 is a graphic illustration of test results obtaining using the apparatus of Fig 11.

Detailed Description of Preferred Embodiments

- [0020] Turning now to the drawings and referring first particularly to Figs. 1 and 2, a typical heating element assembly embodying the present invention and made in accordance with the invention is indicated generally by the reference numeral 10. In the description which follows and in the claims directional terms such as upper and lower are employed for convenience and refer to the illustrated heating element assembly 10 as oriented in the drawings, however, it should be understood that the heating element assembly of the present invention may be operated in any orientation.
- [0021] The illustrated heating element assembly 10 essentially comprises an axially elongated substantially flat bundle of individual continuous carbon fibers or filaments, which cooperate to form a heating element, the flat bundle or heating element being designated generally by the reference numeral 12 and the individual fibers or filaments being indicated at 14, 14. The assembly 10 further includes an outer jacket or electrically insulating sheath, indicated generally at 16, formed by lower and upper layers of relative thin dielectric sheet material 18 and 20, respectively. The layers 18 and 20 are of equal width and thickness, and arranged in opposing face-to-face

relation to each other with the heating element 12 disposed therebetween. The upper face of the lower layer 18 is bonded to the lower surface of the bundle 12, whereas the lower face of the upper layer 20 is disposed in direct contacting engagement with and in unconnected relation to the associated upper surface of the flat bundle 12, which it directly overlies and compliments.

[0022] Longitudinally extending marginal portions of the layers 18 and 20, indicated at 22, 22 and 24, 24, respectively, project outwardly in opposite axially transverse directions for some distances beyond the longitudinally extending opposite sides of the bundle 12 and are joined in face-to-face relation to each other by appropriate connecting and sealing means along each side of the bundle and along substantially the entire axial length of the bundle 12 for preventing migration of moisture transversely through the sheath 16 formed by the connected layers 18 and 20. The connected lower and upper marginal portions 22, 22 and 24, 24, respectively, may also serve as mounting flanges for securing the heating element assembly 10 in an operating position relative to associated product or structure to be heated. In the illustrated embodiment 10 the connecting and sealing means comprise a coating of pressure sensitive adhesive, indicated at 26, best shown in Fig. 2, and initially applied to and carried by the lower layer 18.

[0023] In accordance with presently preferred construction, both the carbon filaments 14, 14, which comprise the heating element or bundle 12, and the layers of dielectric sheet material from which the outer sheath 16 is formed are flexible so that the heating element assembly 10 may be produced in indeterminate length for storage on a dispensing reel or the like and to facilitate flexure during mounting and/or when in use, if necessary. Ultimately, the length of the heating element assembly 10 will be determined by the particular requirements of the product or structure in which it is utilized.

[0024] Considering now the heating element assembly 10 in further detail, in accordance with presently preferred construction, the bundle 12 comprises a generally flat carbon fiber tow having a multiplicity of artificially produced carbon fibers or filaments 14, 14 and a thickness to width ratio of about 1 to 25. The tow may be made from polyacrylonitrile (PAN) or other suitable polymer precursor by a pyrolyzing process, as is well known in the carbon fiber art. The terms carbon fiber

tow and carbon filament tow as used herein, and in the claims, refer to a loose, untwisted, rope-like flat bundle of continuous generally rectilinear parallel carbon fibers extending in an axial direction (i.e. slender and greatly elongated axially extended filaments) which may include from several hundred individual continuous generally rectilinear flexible filaments 14, 14 to several tens of thousands of such filaments and having an electrical resistance in the range from 0.1 to 20 ohms per linear foot. However, in accordance with present practice, a tow having from 1 thousand to 50 thousand generally cylindrical filaments or fibers 14, 14 each having a diameter ranging from 6 to 10 microns and an electrical resistance (cold) in the range of 2 to 3 ohms per linear foot, plus or minus .10 ohm, is used in practicing the invention, a tow having 50,000 filaments of 7 micron diameter being presently preferred.

[0025] A commercial grade carbon fiber tow, that is a tow which is 94-96 percent pure carbon by weight may be employed in practicing the invention. A tow of military grade may also be employed. However, a tow of the later type, which is 98 percent pure carbon by weight, is considerably more expensive to produce and, for this reason, a commercial grade material is presently preferred and should result in a heating element suitable for most heating applications.

[0026] The outer jacket or insulating sheath 16 may be made from any suitable flexible dielectric plastic material. However, since the heating element assembly 10 is designed to operate within a temperature range from approximately minus 100° F to 250° F, the dielectric material chosen for use in making the sheath 16 must be capable of withstanding temperatures within the aforesaid anticipated operating range without undergoing an appreciable change in physical characteristics or a significant increase in its rate of deterioration. The flexible sheath material should also possess the required characteristic which allow it to be bonded to itself or to another material either by a suitable adhesive or by a non-adhesive bonding process which provides a moisture-tight seal of substantial integrity in the region of joinder. As previously noted, a relatively thin plastic sheet material is used in making the heating element jacket 16, MYLAR, a thermoplastic polyester, being a presently preferred material. The sheath may also be made from a polyimide, KAPTON being a preferred material where a sheath of thermosetting material may be desired.

[0027] The entire jacket or sheath 16 may be made from the same material as, for example, polyester sheet or web material having a thickness of two mil (.0002 inch) (.0508 millimeter). However, the upper layer 20 is the preferred heat transfer medium because it is in direct contact with the heating element 12, unlike the lower layer 18 which is or may be separated from the heating element by a layer of adhesive which provides some degree of heat insulation. Since the upper and lower surfaces of the heating element assembly 10 have differing heat transfer characteristics, the assembly is preferably coded to enable one layer to be readily distinguished from the other. A color coding is presently preferred wherein the layers are of differing colors to assure proper mounting and provide the most efficient heat transfer to an associated surface or structure to be heated.

[0028] In Figs. 3 and 4 there is shown another heating element assembly embodying the invention and indicated generally at 10a. Parts of the assembly 10a which correspond to parts of the previously described assembly 10 bear the same numerals as the previously described parts with a letter "a" suffix and will not be further described in detail.

[0029] The assembly 10a differs from the assembly 10 in that it has a generally flat planar lower layer 18a, which is substantially thicker than the upper layer 20a. It will also be noted that the upper layer 20a is made from a web of material substantially wider than the web from which the lower layer 18a is made. The lower layer 18a, that is the layer which is connected to and stabilizes the tow 12a, has a thickness somewhat greater than the thickness of the upper layer or unconnected layer 20a, which preferably comprises the heat transfer medium. Thus, in accordance with a presently preferred construction, the lower layer may, for example, have a thickness of two mil (.0002 inch) (.0508 mm) whereas the thickness of the upper layer 20 may be 1 mil (.0001 inch) (.0254 mm).

[0030] The heating element assembly of the present invention, exemplified by the assembly 10, is preferably produced by a continuous forming process shown somewhat schematically in Fig. 5 wherein the tow 12, which has been preferably previously produced with a flattened cross section configuration, is moisturized and continuously advanced and guided by a set of guide rolls or other suitable guiding means into alignment and overlying engagement with the upper face of a

continuously advancing lower layer or web of polyester sheet material 18, the entire upper face of which is precoated with a pressure sensitive adhesive 26. A continuously advancing second web or upper layer of sheet material 20 is simultaneously guided and fed into overlying engagement with the advancing tow 12 and the advancing first layer 18 which underlies the tow. The advancing subassembly, which includes the tow 12, the adhesive coated lower layer 18 and the uncoated upper layer 20, passes between a set of pressure rollers, indicated generally at 30, which generally compliment the cross-sectional configuration of the aforesaid subassembly. The pressure rollers press the marginal portions 24, 24 of the uncoated upper layer 20 into adhering engagement with complimentary marginal portions 22, 22 of the pressure sensitive adhesive coated lower layer 18. Pressure is simultaneously applied to the central portion of the subassembly to adhere the lower surface of the flattened tow 12 to the adhesive coated upper face of the lower layer 18 whereby to complete formation of the advancing sheath 16, which then embraces the simultaneously advancing flattened tow 12.

[0031] A similar forming process may be employed using a heat-activated adhesive preapplied to the first or lower layer, for example. The adhesive may be activated by heated pressure rolls or other suitable heating mean during the sheath forming process. If a heat-activated adhesive is employed, an additional curing or drying cycle may be included in the process to complete assembly of the sheath 16. Once activated the heat activated adhesive takes a permanent set and remains substantially unchanged even after application of additional heat.

[0032] Various other bonding processes may be employed to join and seal the marginal portions of the upper layer 20 to associated marginal portions of the lower layer 18 and/or to connect the tow 12 to the lower layer 18. Thus, for example, the marginal portions may be joined by an ultrasonic welding process or the simultaneous application of heat and pressure as, for example, where the marginal portions are passed between heated rollers or the like. However, any process employed to attach the upper face of the lower layer to the lower surface of the tow must be capable of effecting attachment without destroying or otherwise damaging the electrical continuity of the elongated fibers or filaments which comprise the tow.

[0033] As previously noted, the length of a heating element assembly will be determined by the particular heating requirements of the product or structure in which it is to be employed. When the required axial length of the heating element assembly has been determined, opposite end portions of the heating element 12 are prepared for electrical termination. More specifically, and with further reference to the assembly 10, a portion of the outer jacket or sheath 16 is removed from each end portion of the heating element assembly 10 to prepare the heating element 12 for electrical termination; that is to facilitate electrical connection to an electrical power source (not shown). Each end portion of the completed heating element assembly 10 is prepared for electrical termination by stripping from the assembly 10 an end portion of the upper layer 20 which overlies the tow 12 and associated marginal end portions 22, 22 and 24, 24 of the upper and lower layers which extent transversely outwardly beyond the tow. Stripping is best accomplished using an electrically heated nickel chromium wire under tension, shown at 31 in Fig. 6. The heated wire 31 is pressed downwardly on the assembly 10 to cut entirely through both upper and marginal portions and through the upper layer 20 down to the upper surface of the tow 12. Since the melting temperature of the sheath 16 is much lower than that of the carbon fiber tow 12, the hot wire stripping operation may be preformed without risk of damaging the tow. Secondary slits, indicated at 32, 32 in Fig. 6, are cut or otherwise formed at opposite sides of the tow 12 and in parallel relation to the direction axial extent of the tow whereby the central end portion of the upper layer 20 and the entire associated marginal end portions formed by the joinder of the lower and upper layers are removed. The resulting stripped terminal end portion of the heating element assembly 10, indicated generally at 34 in Fig. 7, includes an end portion of the tow 12 which extends outwardly beyond the end of the upper layer 20 and an extending tab 35 formed by a portion of the lower layer 18. The tab 35 underlies the extending terminal end portion 34 and is adhered to the lower surface of the terminal end portion. Thus, the bare upper surface of the tow end portion 34 is exposed beyond the cut end of the upper layer 20 to facilitate electrical termination, whereas the extending lower portion or tab 34 on the lower layer 18 remains connected to the lower surface of the tow to stabilize the tow terminal end portion 34. Thus, the relatively fine, delicate exposed end portion of the tow 12 derives support from the extending tab 35

on the lower layer 20 which is adhered to filaments at 14, 14 at the lower surface of the tow so that the resulting exposed terminal end portion 34 can be conveniently handled during a later electrical termination process without substantial risk of damage to the tow.

[0034] Further referring to the drawings and particularly Figs. 8 and 9, another heating element assembly embodying the present invention is indicated generally at 10b. The illustrated heating element assembly 10b essentially comprises a series of axially elongated, axially parallel flexible carbon fiber tows 12b, 12b of undetermined axial length. The tows may vary in number and are spaced apart and have interstacies 36, 36, therebetween. Each tow 12b has a multiplicity of continuous axially parallel carbon filaments 14b, 14b disposed in immediate adjacent relation to each other and a predetermined electrical resistance per unit of tow length. The tows 12b, 12b are sandwiched between opposing first and second layers of polyester sheet material, preferably MYLAR, indicated at 18b and 20b, respectively. The layers 18b and 20b are bonded together in face-to-face relation to each other along the interstacies 36, 36 and along longitudinally extending marginal portions 22b, 22b, located outboard of the outermost tows in the series to form a dielectric outer jacket 16b. The marginal bonds between the layers 18b and 20b have a high degree of sealing integrity to prevent transverse migration of moisture into the jacket 16b through the marginal portions thereof and between the tows within the jacket 16b. The face of one of the layers 18b and 20b is bonded to associated surfaces of the tows 12b, 12b to stabilize the tows as hereinbefore discussed. The other of the layers is disposed in direct contacting engagement with the tows 12b, 12b, but is not connected to the tows, which allows the assembly 10b to be cut to desired length at any point along its entire length. The resulting end portion may be stripped at that time or at a later time for electrical termination, as hereinbefore discussed. The unconnected layer preferably serves as a heat transfer medium when the heating element assembly 10b is mounted in a device or structure to be heated.

[0035] Heating element assemblies in accordance with the invention are adapted to operate within a temperature range, which utilizes to advantage the negative temperature coefficient characteristic of carbon fiber. Thus, when a heating element

assembly of the present invention is operated within such a temperature range, 150°F to 200°F, for example, the electrical resistance of the heating element assembly decreases as the temperature of the heating element increases. The advantage attained by utilizing the aforesaid phenomenon will be better understood from a comparison of a typical carbon fiber heating element assembly and one of a conventional metal type.

[0036] Referring now to Fig. 10, a test apparatus for determining the electrical resistance of the aforesaid heating element network at standard temperature and pressure is illustrated and indicated generally at 40. A carbon fiber tow or heating element 12 of the type used in making the heating element assembly 10 and having 50 thousand carbon fibers of seven micron diameter and a 10 foot length is electrically terminated at 42, 42 by lead conductors 44, 44 suitable for interconnection to electrical instrumentation. A four wire bridge type ohm meter 46 is used to measure the total resistance of the ten-foot network at standard temperature and pressure, whereby the resistance per foot of axial length is determined to be 2.8 ohms/ft.

[0037] The aforescribed network is then connected to another testing apparatus which includes a variable DC voltage source 48 (0-50VDC), an amp meter 50 and a thermometer 52, as shown as in Fig. 11. The voltage is slowly adjusted until the temperature of the carbon fiber tow reaches 150°F. Thereafter, the voltage is increased to produce 10°F increments of temperature increase until the temperature of the network reaches 200°F. The voltage (volts) and amperage (amps) for each 10° incremental increase in temperature is recorded. The electrical resistance for each 10° temperature increment is then calculated by applying ohm's law.

$$V = IR$$

Where V = voltage (volts)

I = current (amps)

R = resistance (ohms)

$$R = \frac{V}{I} = \text{ohms/ft}$$

[0038] A conventional metal heating element of 10 foot length is substituted for the carbon fiber network and the aforesaid test and calculations are repeated and the

results are recorded for the metal heating element sample. The accumulated data is then used to plot the graphic illustration shown in Fig. 12. It will be noted that the resulting curve 54 for the carbon fiber heating element 12 has a negative slope throughout the anticipated operating range, which is characteristic of carbon fiber material, whereas the comparable curve 56 for a metallic heating element exhibits a positive slope throughout the entire anticipated operating range, indicating that electrical resistance increases as the temperature of the heating element material increases when operated within the range under consideration.

[0039] The aforesaid data will allow a designer to implement a carbon fiber heating element system to achieve a desired criteria. A typical heating application employing the aforesaid data developed for a heating element assembly 10 which has a 50 thousand (50K) carbon fiber tow and is designed to operate at 160°F will now be considered.

[0040] Employing the data developed for a 50 K carbon fiber heating element assembly 10 where an element temperature of 160°F is desired:

R @ standard temperature and pressure = 2.8 ohms/ft.

R @ 160°F = 2.2 ohms/ft

I @ 160°F = 1.5 amps

V = IR V = 1.5 x 2.2 = 3.3 volts DC/ft

Applying the data developed for a metal heating element operating at 1.5 amps where

R @ 160°F = 3 ohms/ft

V = 1.5 x 3 = 4.5 volts/foot DC

[0041] An increase in voltage input per foot of 1.2 volts or 27% is required by the metal heating element.

[0042] The development of similar data should enable a designer to implement a carbon fiber heating element assembly to achieve a desired criteria.